

**Thermal Management Of An Optical Amplifier  
Module Housed In A Universal Cable Joint**

**Related Applications**

[0001] This application is related to U.S. Patent Application Serial No. 10/687,547 filed October 16, 2003, entitled "Optical Amplifier Module Housed In A Universal Cable Joint".

[0002] This application is also related to U.S. Patent Application Serial No. 10/715,330 filed November 17, 2003, entitled "Method and Apparatus For Electrically Isolating An Optical Amplifier Module Housed In A Universal Cable Joint."

**Field Of The Invention**

[0003] The present invention relates to the field of optical repeaters, and more particularly to an optical repeater employed in an undersea optical transmission system.

**Background Of The Invention**

[0004] In undersea optical transmission systems optical signals that are transmitted through an optical fiber cable become attenuated over the length of the cable, which may span thousands of miles. To compensate for this signal attenuation, optical repeaters are strategically positioned along the length of the cable.

[0005] In a typical optical repeater, the optical fiber cable carrying the optical signal enters the repeater and is coupled through at least one amplifier and various components, such as optical couplers and decouplers, before exiting the repeater. These optical components are coupled to one another via optical fibers. Repeaters are housed in a sealed structure that protects the repeaters from environmental damage. During the process of deployment, the optical fiber cable is coiled onto large drums located on a ship. Consequently, the repeaters become wrapped about the drums along with the cable. Due to the nature of the signals, and the ever increasing amount of information being transmitted in the optical fibers, repeaters are getting larger, and their increased length creates problems as they are coiled around a drum. Although the drums may be up to 9-12 feet in diameter, current repeaters may be greater than 5 feet in length, and, therefore, are not able to lie flat, or even substantially flat, along a drum. Tremendous stresses due to

forces on the order of up to 100,000 pounds are encountered at the connection point between the repeater and the fiber optic cable to which it is attached, especially during paying out and reeling in of the cable. The non equi-axial loading across the cable may arise as a result of severe local bending that is imposed on the cable at its termination with the repeater. This loading would inevitably lead to failure of cable components at loads well below the tensile strength of the cable itself.

[0006] To prevent failure of the cable during deployment of the repeater, a bend limiter is often provided, whose purpose is to equalize the forces imposed on the cable. In addition, a gimbal may be provided at each longitudinal end of the repeater to which the bend limiting devices are attached. The gimbal provides free angular movement in two directions. The bend angle allowed by the gimbal between the repeater and bend limiting device further reduces the local bending that is imposed on the optical fiber cables.

[0007] The large physical size of conventional repeaters increases their complexity and cost while creating difficulties in their deployment.

### **Summary of the Invention**

[0008] In accordance with the present invention, an optical amplifier module is provided that contains at least one optical amplifier. The module includes an internal housing having an outer dimension substantially equal to an outer dimension of an internal fiber splice housing of an undersea optical fiber cable joint. The internal housing includes a pair of opposing end faces each having a retaining element for retaining the internal housing within an outer housing of the undersea optical fiber cable joint. The internal housing also includes a sidewall interconnecting the opposing end faces, which extends between the opposing end faces in a longitudinal direction. The sidewall, which is formed from a thermally conductive material, includes a receptacle portion having a plurality of thru-holes each being sized to receive a passive optical component employed in an optical amplifier. The module also includes at least one circuit board on which resides at least one voltage dropping element for conveying voltage from the conductor to electronics also residing on the circuit board and associated with the optical amplifier. An isolated electrical path provides electrical power received from a conductor in at least one

optical fiber cable to the at least one circuit board. The voltage dropping element is in thermal communication with the sidewall.

**[0009]** In accordance with one aspect of the invention, at least one optical pump source is in thermal contact with one of the end faces.

**[0010]** In accordance with another aspect of the invention, the end faces each include at least one inwardly extending boss. The optical pump source residing on one of the inwardly extending bosses.

**[0011]** In accordance with another aspect of the invention, a first side of the circuit board resides on a surface extending through the sidewall. A thermally conductive pad is mounted to the first side of the circuit board and provides a thermally conductive path between the voltage dropping element and the sidewall.

**[0012]** In accordance with another aspect of the invention, the voltage dropping element is mounted to the thermally conductive pad.

**[0013]** In accordance with one aspect of the invention, the undersea optical fiber cable joint includes a pair of cable termination units in which end portions of optical fiber cables to be jointed are respectively retained. The retaining elements are each connectable to one of the cable termination units.

**[0014]** In accordance with another aspect of the invention, the conductor of each of the optical fiber cables to be jointed are in electrical contact with one of the retaining elements.

**[0015]** In accordance with another aspect of the invention, the isolated electrical path includes a power conductor located within the circuit board that is in electrical contact with one of the retaining elements.

**[0016]** In accordance with another aspect of the invention at least one voltage dropping element is provided for conveying a portion of voltage from the power conductor to the electronics associated with the optical amplifier.

**[0017]** In accordance with another aspect of the invention, the voltage dropping element is a zener diode.

**[0018]** In accordance with another aspect of the invention, the circuit board

comprises a pair of circuit boards, and the isolated electrical path further includes at least one electrically conductive pin electrically connecting the power conductors of the pair of circuit boards.

**[0019]** In accordance with another aspect of the invention, the plurality of thru-holes laterally extend through the receptacle portion of the sidewall in the longitudinal direction.

**[0020]** In accordance with another aspect of the invention, the internal housing has a generally cylindrical shape. The receptacle portion of the sidewall has a curvature that defines a diameter of the cylindrical shape.

**[0021]** In accordance with another aspect of the invention, the undersea optical fiber cable joint is a universal joint for jointing optical cables having different configurations.

**[0022]** In accordance with another aspect of the invention, the universal joint includes a pair of cable termination units in which end portions of the optical cables to be jointed are respectively retained. The retaining elements are each connectable to one of the cable termination units.

**[0023]** In accordance with another aspect of the invention, the retaining elements each include a flange through which at least one optical fiber extending from the end portion of one of the optical cables extends into the internal housing.

**[0024]** In accordance with another aspect of the invention, the optical fiber storage area includes at least one optical fiber spool around which optical fiber can be wound.

**[0025]** In accordance with another aspect of the invention, the internal housing is formed from a pair of half units that each include one of the retaining elements.

**[0026]** In accordance with another aspect of the invention, the sidewall includes a pair of ribbed members extending longitudinally from the receptacle portion of the sidewall. The ribbed members each have a tension rod thru-hole extending laterally therethrough in the longitudinal direction for supporting a tension rod employed by the undersea optical fiber cable joint.

**[0027]** In accordance with another aspect of the invention, the outer dimension of the internal housing is less than about 15 cm x 50 cm.

**[0028]** In accordance with another aspect of the invention, the outer dimension of the internal housing is about 7.5 cm x 15 cm.

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### **Brief Description of the Drawings**

- [0029] FIG. 1 shows an example of an undersea optical fiber cable.
- [0030] FIG. 2 shows a simplified schematic diagram of a universal cable joint for jointing fiber optic cables for use in undersea optical telecommunication systems.
- [0031] FIG. 3 shows a particular example of a universal cable joint that is available from Global Marine Systems Limited and the Universal Joint Consortium.
- [0032] FIG. 4 shows a side view of an optical amplifier module constructed in accordance with the present invention.
- [0033] FIG. 5 shows a perspective view of one of the half units that form the optical amplifier module depicted in FIG. 4.
- [0034] FIG. 6 shows a side view of one of the half units that form the optical amplifier module depicted in FIG. 4.
- [0035] FIG. 7 shows a cross-sectional side view one of the half units that form the optical amplifier module depicted in FIG. 4.
- [0036] FIG. 8 is cross-sectional side view of the optical amplifier module shown in FIG. 4.
- [0037] FIG. 9 is an enlarged, cross-sectional side view of the portion of the optical amplifier module that interconnects with the end cap.
- [0038] FIG. 10 shows a plan view of the bottom of one of the circuit boards illustrating the manner in which the zener diodes are mounted to facilitate heat transfer.

### **Detailed Description**

- [0039] The present inventors have recognized that a substantially smaller repeater can be achieved by first reducing the length of the repeater so that the stresses placed upon it during its deployment are greatly reduced, thereby eliminating the need for gimbals. The elimination of the gimbals, in turn, allows further reductions in the dimensions of the repeaters.
- [0040] The present inventors have further recognized that a repeater substantially reduced in size can be housed in a unit formed from off-the-shelf components that have been qualified for the undersea environment. In particular, the inventors have recognized that a housing conventionally used for interconnecting different undersea optical fiber

cables can also be used as an ultra-small form-factor repeater housing. As discussed below, one such housing, commonly referred to as the Universal Joint, has become the defacto worldwide standard for maintaining submarine cables and has a lengthy history of successful deployment. The present invention thus provides a repeater that, because of its small size, is easily deployed and which is located in an economical, submarine qualified housing that is already well established in the undersea optical communications industry. Moreover, because the Universal Joint can interconnect different optical fiber cables, the repeater can be used to interface with a variety of cables and systems from different manufacturers.

**[0041]** To facilitate an understanding of the present invention, an example of an undersea optical fiber cable will be described in connection with FIG. 1. While different cable manufactures employ cables having different configurations and dimensions, most cables employ most of the components depicted in FIG. 1 in one form or the other.

Optical cable 330 comprises a single, centrally located gel-filled buffer tube 332 made from a metal such as aluminum or stainless steel. The gel-filled buffer tube 332 contains optical fibers 335. In some cases the buffer tube 332 is replaced with a centrally disposed kingwire that is surrounded by optical fibers that are embedded in a polymer. Two layers of strandwires, which serve as strength members, are wound around the buffer tube. One layer includes strandwires 338 and the other layer includes strandwires 339. A copper conductor 340 surrounds the strandwires and serves as both an electrical conductor and a hermetic barrier. An outer jacket 342 formed from polyethylene encapsulates the copper conductor 340 and serves as an insulating layer.

**[0042]** FIG. 2 shows a simplified schematic diagram of a universal cable joint for joining fiber optic cables for use in undersea optical telecommunication systems. Such a joint is referred to as a universal cable joint because it can interconnect many different types of undersea optical telecommunication cables, regardless of manufacturer. The cable joint includes a common component assembly 10 in which an optical fiber splice is located. The fiber splice is formed from two fibers that respectively originate in two cables that each terminate in cable termination units 12. A protective assembly 15 surrounds common component assembly 10 and cable termination units 12 to provide protection from the external environment.

[0043] FIG. 3 shows a particular example of a universal cable joint that is available from Global Marine Systems Limited and the Universal Joint Consortium, which, as previously mentioned, is often simply referred to as the Universal Joint. In FIGs. 2 and 3, as well as the figures that follow, like reference numerals indicate like elements. In FIG. 3, the protective assembly 15 depicted in FIG. 2 comprises a stainless steel sleeve 14 that surrounds the common component assembly 10 and a polyethylene sleeve 16 that is molded over the common component assembly 10. The stainless steel sleeve 14 provides resistance to tensile, torsional and compressive loads and further provides an electrically conductive path through which electrical power can be transmitted from the copper conductor of one cable to the copper conductor of the other.

[0044] The jointing process begins by stripping back the various layers of the cable to reveal predetermined lengths of the outer jacket, copper conductor, strandwires, and the fiber package (e.g., the buffer tube containing the optical fibers or the kingwire surrounded by the optical fibers). The strandwires are clamped in a ferrule assembly located in the cable termination units 12. The fiber package extends into the common component assembly 10, where it is held in place by a series of clamps. In the common component assembly 10 the individual fibers are separated and spliced to their corresponding fibers from the other cable. The splices, along with excess fiber, are looped and wound in channels that are formed within the common component assembly 10. The common component assembly 10 is inserted in the stainless steel sleeve 14 and end caps 13 are screwed to each end of the assembly 10. Two tension rods 17 and 19 extend through the end caps 13 and the common component assembly 10. The tension rods 17 and 19 are designed to carry the tension loads that are placed on the universal joint during the deployment process as the joint is transferred from a ship to its undersea environment. Finally, the joint is laid in a mold that is injected with molten polyethylene to provide an insulate (i.e., polyethylene sleeve 16) that is continuous with the outer jacket of the cables.

[0045] The present inventors have recognized that a cable joint such as the universal cable joints depicted in FIGs. 2-3 can be modified to serve as a repeater housing in which 1 or more optical amplifiers are located. FIGs. 4-9 show one embodiment of an optical amplifier module 400 that replaces the common component assembly 10 seen in FIGs. 1-

4. The optical amplifier module 400 must have substantially the same dimensions as the common component assembly, which is only about 7.5 cm x 15 cm. As previously mentioned, this is far less in size than conventional repeater housings, which are often several feet in length. The optical amplifier module 400 depicted in the figures can support 4 erbium-doped fiber amplifiers (EDFAs), physically grouped as a dual amplifier unit for each of two fiber pairs. Of course, the present invention encompasses optical amplifier modules that can support any number EDFAs.

[0046] Each optical amplifier includes an erbium doped fiber, an optical pump source, an isolator and a gain flattening filter (GFF). The amplifiers are single-stage, forward pumped with cross-coupled pump lasers. A 3 dB coupler allows both coils of erbium doped fiber in the dual amplifier to be pumped if one of the two pump lasers fails. At the output, an isolator protects against backward-scattered light entering the amplifier. The gain flattening filter is designed to flatten the amplifier gain at the designed input power. An additional optical path may be provided to allow a filtered portion of the backscattered light in either fiber to be coupled back into the opposite direction, allowing for COTDR-type line-monitoring. Of course, optical amplifier module 400 may support EDFAs having different configurations such as multistage amplifiers, forward and counter-pumped amplifiers, as well as fiber amplifiers that employ rare-earth elements other than erbium.

[0047] The optical amplifier module 400 is designed to be compatible with the remainder of the cable joint so that it connects to the cable termination units 12 and fits within the stainless steel sleeve 14 in the same manner as the common component assembly 10.

[0048] A side view of optical amplifier module 400 is shown in FIG. 4 with end caps 13 in place. The module 400 is defined by a generally cylindrical structure having flanges 402 (seen in FIG. 5) located on opposing end faces 403. A longitudinal plane 405 extends through the optical amplifier module 400 to thereby bisect the module 400 into two half units 404 and 404' that are symmetric about a rotational axis perpendicular to the longitudinal plane 405. That is, as best seen in FIG. 5, rather than dividing the end faces 403 into two portions located on different half units 404, each half unit 404 includes the portion of one of the end faces 403 on which a respective flange 402 is located. FIG. 5



shows a perspective view of one of the units 404. In the embodiment of the invention depicted in FIGS. 4-9, each half unit 404 houses two erbium-doped fiber amplifiers

[0049] Flanges 402 mate with the cable termination units 12 of the Universal Joint shown in FIG. 3. As seen in the cross-sectional views of FIGs. 7 and 8, through-holes 407 extend inward from the end faces 403 through which the tension rod of the universal joint are inserted. The end faces 403 also include clearance holes 430 for securing the end caps 13 of the Universal Joint to the optical amplifier module 400. The clearance holes 430 are situated along a line perpendicular to the line connecting the tension rods thru-holes 407.

[0050] As shown in FIGs. 4-6, each unit 404 includes curved sidewalls 412 forming a half cylinder that defines a portion of the cylindrical structure. A spinal member 406 is integral with and tangent to the curved sidewalls 412 and extends longitudinally therefrom. The thru hole 407 containing the tension rod of the universal joint extends through the spinal member 406. A ceramic boss 440 is located on the end of the spinal member 406 remote from the end flange 403. As shown in FIGs. 5 and 7, the thru hole 407 extends through the ceramic boss 440. As discussed below, the ceramic boss 440 prevents the flow of current from one half unit 404 to the other.

[0051] A circuit board support surface 416 extends along the periphery of the unit 404 in the longitudinal plane 405. Circuit board 426 is mounted on support surface 416. When the half units 404 and 404' are assembled, circuit boards 426 and 426' are interconnected by a pair of interlocking conductive power pins 423 that provide electrical connectivity between the two circuit boards 426 and 426'. The inner cavity of the unit 404 located between the circuit board support surface 416 and the spinal member 406 serves as an optical fiber storage area. Optical fiber spools 420 are located on the inner surface of the spinal member 406 in the optical fiber storage area. The erbium doped fibers, as well as any excess fiber, are spooled around the optical fiber spools 420. The optical fiber spools 420 have outer diameters that are at least great enough to prevent the fibers from bending beyond their minimum specified bending radius.

[0052] The curved sidewalls 412 are sufficiently thick to support a plurality of thru-holes 418 that extend therethrough in the longitudinal direction. The thru-holes 418 serve as receptacles for the passive components of the optical amplifiers. That is, each

receptacle 418 can contain a component such as an isolator, gain flattening filter, coupler and the like.

[0053] End faces 403 each include a pair of pump support bosses 403a (see FIGs. 6 and 7) that extend inward and parallel to the circuit board 426. The circuit board 426 has cut-outs so that the pump support bosses 403a are exposed. A pump source 427 that provides the pump energy for each optical amplifier is mounted on each pump boss 403a.

#### ELECTRICAL CONNECTIVITY

[0054] As previously mentioned, electrical connectivity must be maintained between the cables in the two cable termination units 12. However, the various components in the optical amplifier module 400 must be electrically isolated to enable a small voltage (e.g., 5-20v) that must be supplied to the electrical components located on the circuit boards 426.

[0055] Referring again to FIG. 3, the optical amplifier module 400 and sleeve 14 are surrounded by polyethylene sleeve 16, which serves as a dielectric. Electrical power is taken from the conductor in the cable located in the termination units 12 and transferred through a conductor located in the circuit board 426. The circuit board is electrically isolated from the optical amplifier module 400, with the epoxy resin of the circuit board acting as a local dielectric. After the voltage is dropped to the electrical components on one of the circuit boards the voltage is passed from circuit board 426 to circuit board 426' via a pair of compliant conductive pins 423 that each comprise a pin and socket assembly. The pins 423 allow for any axial movement that may occur as a result of tension or hydrostatic pressure.

[0056] More specifically, with reference now to FIGS 7 and 8, power is supplied to the electrical components as follows. Since the cable termination units 12 are electrically powered or active, end caps 13 are also electrically active. A power conductor extends within each of the circuit boards 426 and 426'. The power conductors receive electrical power directly from the pump support bosses 403a. One or more voltage dropping elements such as zener diodes are located on the circuit board 426. The zener diodes, which electrically couple the power conductors to the other electrical components on the circuit board, drop a voltage that is sufficient to power the electrical components. Electric

connectivity extends along the power conductors and is maintained across the circuit boards to the other via the conductive pins 423. In this way electric conductivity extends from one end cap 13, through the end flange 403 and pump support boss 403a in contact with the end cap 13, through the power conductor located on the circuit board 426 resting on the pump support boss 403a, through one of the power pins 423 and through the power conductor located in the other circuit board 426. Finally, electrical conductivity extends to the other end cap 13 via the other pump support boss 403a and end flange 403.

[0057] The electrical path is isolated from the optical amplifier module 400 as follows. An electrically insulating pad is located between the circuit board support surface 416 and the circuit board 426. In this way the pump support boss 403a is electrically isolated from the circuit board 426, except through the aforementioned power conductor. Ceramic isolators 442 surround the bolts that secure the circuit board 426 to the sidewalls 412 of each half unit 404. The ceramic isolators 442 prevent electrical discharges from the bolts to the components located on the circuit board 426. The ceramic boss 440 located on each half unit 404 electrically isolates the spinal member 406 to which it is connected from both the end cap 13 and the end flange 403 with which it is in contact.

[0058] FIG. 9 shows the manner in which the tension rods 409 extending through thru-holes 407 are electrically isolated from the end caps 13. As shown in FIG. 9 for the left-most end cap 13, a ceramic washer 444 surrounds the head of each tension rod 409. The ceramic washer 444 electrically isolates the end cap 13 from the tension rod 409. Because the seal established by the ceramic washer 444 is not hermetic, copper washers 446 and 448 are also provided to ensure that such a hermetic seal is achieved between the tension rod and the end cap 13. The threaded end of the tension rods 409 terminate in the opposing end cap 13 and the threaded ends are not electrically isolated from the end cap 13.

[0059] Since the sleeve 14 contacts the end caps 13, sleeve 14 should preferably be formed from a non-conductive material. For example, sleeve 14 may be formed from a thermally conductive ceramic, which is advantageous because of its strength. However, because such ceramics are often nominally electrically conductive they need to be

provided with an oxide surface in order serve as a dielectric. The surface finish of the oxide is preferably polished to facilitate formation of a hermetic seal.

## THERMAL MANAGEMENT

[0060] The pump sources 427 and zener diodes generate a significant amount of heat that must dissipated to ensure that the temperature of the various components do not exceed their operational limits. This is a particularly challenging problem because the pump sources 427 and zener diodes may generate several watts of power over a small area. Moreover, the thermal energy must be dissipated while simultaneously achieving electrical isolation of these same components, two goals which are clearly somewhat at odds with one another. As detailed below, a number of features of the optical amplifier module 400 enhance thermal management so that the heat is adequately dissipated.

[0061] As previously mentioned, pump sources 427 are mounted on the pump support bosses 403a of the end flange 403. The heat from the pump sources 427 is thereby conducted through the pump support bosses 403a to the end flange 403, which has a relatively large mass so that it serves as an effective heat sink. The end flange 403 in turn conducts the heat to the end caps 13 seen in FIG. 3.

[0062] The sidewalls 412 of the optical amplifier module 400 are made from a thermally conductive material such as a metal, preferably aluminum. Since the sidewalls 412 have a relatively large surface area, they serve as a spreader that distributes the heat over its surface in a uniform manner so that its local and overall temperature rises are kept to a minimum. The zener diodes are preferably situated as close to the sidewalls 412 as possible to so that the heat generated by the diodes can be readily conducted to the sidewalls 412.

[0063] For example, as best seen in FIG. 10, in one embodiment of the invention the zener diodes 484 are located on the bottom of the circuit board 426 (i.e., the side of the circuit board opposite from that on which the pump sources 427 reside). Copper pads 480 are located on this bottom surface, below each of the ceramic isolators 442 that isolates bolts 482 that secure the circuit board 426 to the support surface 416. The zener diodes 484 are mounted on the copper pads 480, adjacent to the bolts 482. The copper pads 480

serve as one of the electrical contacts for each of the zener diodes 484, the other of which is denoted by reference numeral 486. A portion of each copper pad 480 resides on the circuit board support surface 416. The copper pads 480 contact the electrically insulating pad on which the circuit board 426 rests. The electrical insulating pad is a relatively good thermal conductor and thereby conducts the heat generated by the zener diodes 484 from the copper pads 480 to the circuit board support surface 416 of the optical amplifier module 400. In this way heat flows from the zener diodes 484, through the copper pads 480 and the electrical insulating pad, and into the optical amplifier module 400. Once the heat has been distributed over the sidewalls 412 of the module 400 the heat is directly conducted to the stainless steel sleeve 14 that surrounds module 400.

[0064] The wide distribution of heat over the relatively large surface area of the end caps 13 and the tension sleeve 14 allows the heat to be effectively conducted through the surrounding polyethylene sleeve 16, which is not a particularly good thermal conductor, to sea water.